FTD-HT-23-80-69

FOREIGN TECHNOLOGY DIVISION

THE EXCITATION OF A GENERATOR-AMPLIFIER SYSTEM

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FTD-HT-23-80-69

EDITED TRANSLATION

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English pages: 7

Source: AN SSSR. Doklady (Academy of Sciences of the Belorussian SSR. Reports), Vol. 10, No. 12, 1966, pp. 929-932.

Translated by: H. Peck/TDBRO-2

DATA HANDLING PAGE

01-ACCESSION NO. / 98-DOCUMENT LOC	TP9000812
39-TOPIC TAGS	laser emission, molecular amplifier, feedback amplifier, laser optic material, laser cavity
09-TITLE	THE EXCITATION OF A GENERATOR-AMPLIFIER SYSTEM
47-SUBJECT AREA	20
42-AUTHOR/CO-AUTHORS	CHECHENINA, YE. P.;16-KATSEVA, I. R.
10-DATE OF INFO	----66
43-SOURCE	AN BSSR. DOKLADY (RUSSIAN)
68-DOCUMENT NO.	FTD-HT-23-80-69
69-PROJECT NO	72301-74
63-SECURITY AND DOWNGRADING INFORMATION	UNCL, 0
64-CONTROL MARKINGS	NONE
97-HEADER CLASN	UNCL

76-REEL FRAME NO.	77-SUPERSEDES	78-CHANGES	40-GEOGRAPHICAL AREA	NO OF PAGES
1889 0297			UR	7

CONTRACT NO.	X REF ACC. NO.	PUBLISHING DATE	TYPE PRODUCT	REVISION FREQ
	65-AP7003279	94-00	TRANSLATION	NONE

STEP NO.	ACCESSION NO.
02-UR/0250/66/010/012/0929/0932	

ABSTRACT

(U) Making use of a procedure developed in an earlier paper (DAN BSSR v. 9, 10, 1965), the authors calculate the emission produced by a generator-amplifier system with allowance for their mutual influence (i.e., the feedback between the generator and the amplifier), for different parameters of the active medium and of the resonator. The properties of such a system are compared with those of a system in which the quantum generator and the quantum amplifier are considered separately, so as to determine the region of parameters in which the feedback must be taken into account. The calculation is based on energy relations with allowance for the dependence of the gain of the active medium on the radiation density. A computer (Minsk-1) was used for the calculations. The results are presented in the form of plots of the emission flux against the relative reflection coefficients and of the emitted energy on the relative reflection coefficient. The investigation shows that the mutual influence of the generator and the amplifier in such a compound system must be taken into account if the amplifier length is shorter than or equal to the length of the driver generator, or when the amplifying section is long but the reflection coefficients are close to the threshold values. This report was presented by Academician AN BSSR B. I. Stepanov. Orig. art. has: 2 figures.

THE EXCITATION OF A GENERATOR-AMPLIFIER SYSTEM

Ye. P. Chechenina and I. R. Katseva

(Presented by Academician B. I. Stapanov, Academy
of the Belorussian SSR)

A number of authors [1-7] have investigated composite solid-state and gas systems in which one of the elements is a master generator and the other is an amplifier. In the theoretical description of such systems the amplifier is often considered separately from the generator [1, 4, 5]. But in a number of cases such an independent examination can lead to erroneous results. In this report the excitation of the generator-amplifier system is studied with consideration of their mutual influence, i.e., feedback between generator and amplifier with different parameters of the active material and the resonator. The features of such a system have been compared with those of a system with independent examination of the generator and amplifier, which permits explaining the region of parameters in which feedback should be considered. The calculation is conducted on the basis of energy relations with consideration of the dependence of the amplification factor of the active material on the radiation density. The method used is discussed in reports [8, 9]. The obtained results relate to currents which are integral in frequency and angle.

The excitation of a composite generation system made of two series-arranged samples is investigated in detail in [8]. In it, it is shown that values of amplification X_1 and X_2 (for one pass) can be determined from the system of equations

$$X_1^2 X_2^2 r_1 r_3 (t_2 - r_2'' r_2') + X_1^2 r_1 r_2' + X_2^2 r_3 r_2'' - 1 = 0, \tag{1}$$

$$\frac{\frac{s_0}{\alpha_1}\left[k_{01} - \rho_1 - \frac{1}{\ell_1}\ln X_1\right]\left(\rho_2 + \frac{1}{\ell_2}\ln X_2\right)\ln X_1}{\frac{s_0}{\alpha_2}\left[k_{02} - \rho_2 - \frac{1}{\ell_2}\ln X_2\right]\left(\rho_1 + \frac{1}{\ell_1}\ln X_1\right)\ln X_2} =$$

$$= \frac{(1 - X_2^2 r_2'' r_3)[(1 - r_1) + X_1 r_1 (1 - r_2')] - X_1^2 X_2^2 r_1 r_3 t_2^2}{X_1 t_2 r_1 [X_2 (1 - r_3) + X_2^2 r_3 - 1]},$$

where r_1, t_1 and r_3, t_3 are the reflectivity and transmissivity of the external mirrors; r_2' and r_2'' are the reflectivities of the intermediate layer on the part of the first and second samples, respectively; k_{0j} ($j = 1, 2$) are the initial amplification factors; ρ_j are the spurious loss factors; ℓ_j are the lengths of the amplifying layers; and t_2 is the transmissivity of the intermediate layer. Knowing X_1 and X_2 it is not difficult to calculate the value of currents coming out of the composite system. Thus, for example, for a current coming out through the right end we have [8]

$$S_{out} = \frac{v s_0}{\alpha_2} \frac{\left(k_{02} - \rho_2 - \frac{1}{\ell_2}\ln X_2\right)\ln X_2}{\left(\rho_2 + \frac{1}{\ell_2}\ln X_2\right)[X_2(1 - r_3) + X_2^2 r_3 - 1]} X_2 t_2. \tag{2}$$

Expressions (1) and (2) are also applicable for investigating the excitation of the generator-amplifier system with consideration of coupling between them. Formulas (1) describe not only the amplification process itself, but also the reverse influence of the second sample on the first (values X_1 depend on the properties of the second sample).

Since the generation threshold of the first sample has been overcome (it generates in the absence of the second amplifying layer),

$$k_{01} > \rho_1 + \frac{1}{\ell_1} \ln \frac{1}{\sqrt{r_1 r_2}} = k_{01}^{thr}. \tag{3}$$

For the amplifying layer the following inequality is satisfied:

$$k_{02} < \rho_2 + \frac{1}{\ell_2} \ln \frac{1}{\sqrt{r_2 r_3}} = k_{02}^{thr}. \tag{3'}$$

For simplification it is assumed in (3) and (3') that the reflecting layer between the active samples is characterized by uniform reflectivities from both sides, i.e., $r_2' = r_2'' = r_2$. It is expedient to assume that the external boundary of the master generator completely reflects light ($r_1 = 1$, an opaque mirror), since the values $r_1 = 1$ are encountered most often in practice. From (3) and (3') it follows that at set values of k_{0j}, ρ_j, ℓ_j, and $r_1 = 1$, reflectivities r_2 and r_3 should satisfy the conditions

$$\begin{gathered} 1 > r_2 > e^{-2(k_{01}-\rho_1)l_1} = r_2^{\text{thr}}, \\ 0 \leqslant r_3 < \frac{e^{-2(k_{02}-\rho_2)l_2}}{r_2} = r_3^{\text{thr}}. \end{gathered} \tag{4}$$

In Fig. 1 there are represented the dependences, on r_3, of a current coming out of the generator-amplifier system, with and without consideration of the reverse influence of the amplifier on the generator at different lengths of the amplifying sample ℓ_2, the reflectivities of intermediate boundaries r_3, and the two values of the original amplification factor. The first case corresponds to solid-state lasers ($k_0 = 0.15\ \text{cm}^{-1}$, and the second case corresponds to gas lasers ($k_0 = 0.0015\ \text{cm}^{-1}$)). The calculations are made for $k_{01} = k_{02} = k_0$, $\alpha_1 = \alpha_2 = \alpha$ and $\rho_1 = \rho_2 = \rho$. Mirror absorption was taken into consideration for the gas lasers; the absorptivity of the mirrors was taken as 0.002r.

The computations were done on a "Minsk-1" computer by the iteration method. The current was computed without considering the reverse influence of the amplifier on the generator according to the formulas of report [9].

From Fig. 1 it follows that with short lengths of amplification layer ℓ_2 less than or equal to ℓ_1 (Figs. 1a, d), curves $S_{out}(r_3)$, calculated with and without consideration of the mutual influence have a completely different form. In these cases the second sample is in an amplification regime in the entire region of the change of r_3 from zero to one ($r_3^{\text{thr}} > 1$, and $0 \leq r_3 < r_3^{\text{thr}}$). With consideration of the mutual influence, the dependence on r_3 is more complex.

With an increase of reflectivity r_3 on the output end and with values of r_2 close to r_2^{thr}, outgoing current S_{out} first increases, achieves a maximum value, and then decreases with a further increase of r_3 up to r_3^{thr}. At high values of r_2 the maximum vanishes, and an increase of r_3 up to r_3^{thr} leads to a monotonic increase of the current coming out of the generator-amplifier system. On the curves without consideration of the mutual influence there is no maximum, and the highest value of the output current is obtained at $r_3 = 0$. The dependence on r_3 is continuous, and with an increase of r_3 to r_3^{thr} the output current vanishes.

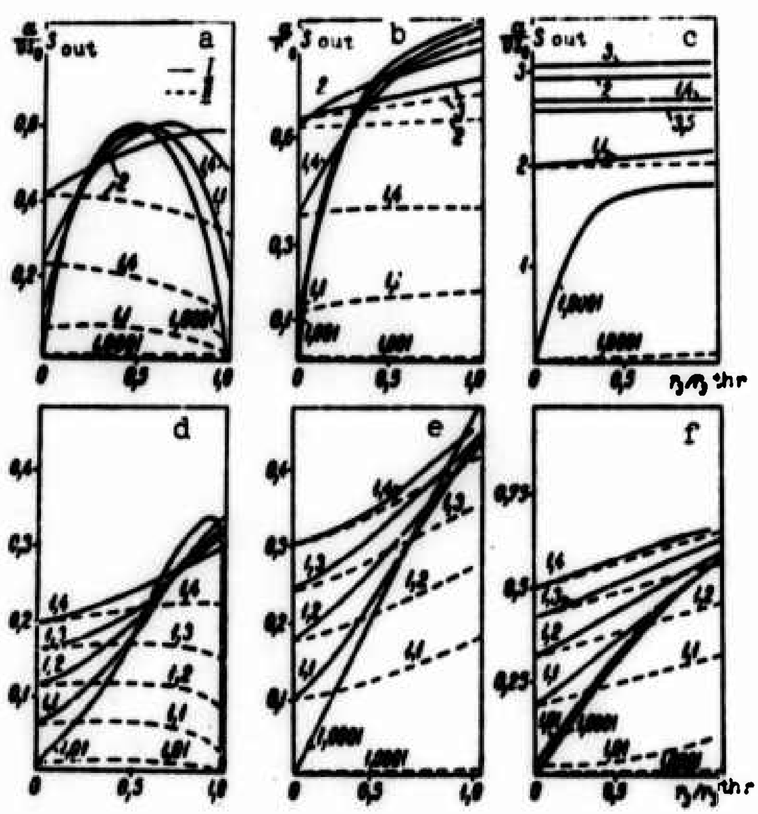

Fig. 1. Dependence of current $\frac{\alpha}{vs_0} S_{out}$ on r_3/r_3^{thr} with (I) and without (II) consideration of the reverse influence of the amplifier on the generator: a, b, c – for $k_0 = 0.15\ cm^{-1}$; $\rho = 0.02\ cm^{-1}$; $\ell_1 = 5$ cm and for ℓ_2 equal to 5 cm, 10 cm, and 50 cm, respectively; d, e, f – for $k_0 = 0.0015\ cm^{-1}$; $\rho = 2.10^{-5}\ cm^{-1}$; $\ell_1 = 150$ cm and ℓ_2 equal to 150 cm, 500 cm, and 1000 cm, respectively. The numbers near the curve are the values of r_2/r_2^{thr}.

With an increase of ℓ_2 and r_2, the values of r_3^{thr} decreases, i.e., the region of the change of r_3 ($0 \leq r_3 < r_3^{thr}$) within whose limits the threshold of the generation of the second sample has not yet been overcome, narrows down. With high lengths of the amplifying layer (Figs. 1b, e) an increase of reflection on the output end in both cases (with and without consideration of feedback) leads to an increase of the current coming out of the generator-amplifier system. With reflectivities of the intermediate layer r_2 close to r_2^{thr}, the emerging currents calculated with the consideration of the feedback many times exceed the currents calculated without considering it. With high reflectivities of r_2 when the coupling between the samples decreases, curves $S_{out}(r_3)$ coincide in both cases. Finally, with sufficiently long lengths of the amplifying layer the output currents in both cases are practically the same.

As a result of the effect of the amplifier on the generator, the energy emerging beyond the limits of the generator depends not only on the parameters of the generator itself, but also on the parameters of the amplifier. It can be calculated from the formula

$$W_1 = \frac{vs_0}{a_1}\left(k_{01} - \rho_1 - \frac{1}{l_1}\ln X_1\right)\frac{\ln X_1}{\rho_1 + \frac{1}{l_1}\ln X_1}. \qquad (5)$$

In Fig. 2 the dependences of W_1 on r_3 have been constructed. From the figure it is obvious that with very short lengths of amplifying layer ℓ_2 (Figs. 2a, d) and with low values of r_2, with an increase of r_3 the magnitude of the energy first increases, i.e., the presence of the amplifier contributes to a more effective use of the energy of the generator itself. At some value of r_3 the maximum value of W_1 is attained, and then the energy taken from the generator decreases. Value r_3 corresponding to the maximum value of W_1 is close to the value of r_3 at which the maximum radiation of the generator-amplifier system is obtained. With comparatively long lengths of the amplifying layer an increase of the reflection on the output end of the amplifier increases W_1, whereupon the greater the r_2, the less the dependence of W_1 on r_3 is expressed. With very long lengths of the amplifying layer, magnitude W_1 is practically independent of r_3, since r_3^{thr} is close to zero, and the mutual influence of the generator and amplifier can be disregarded.

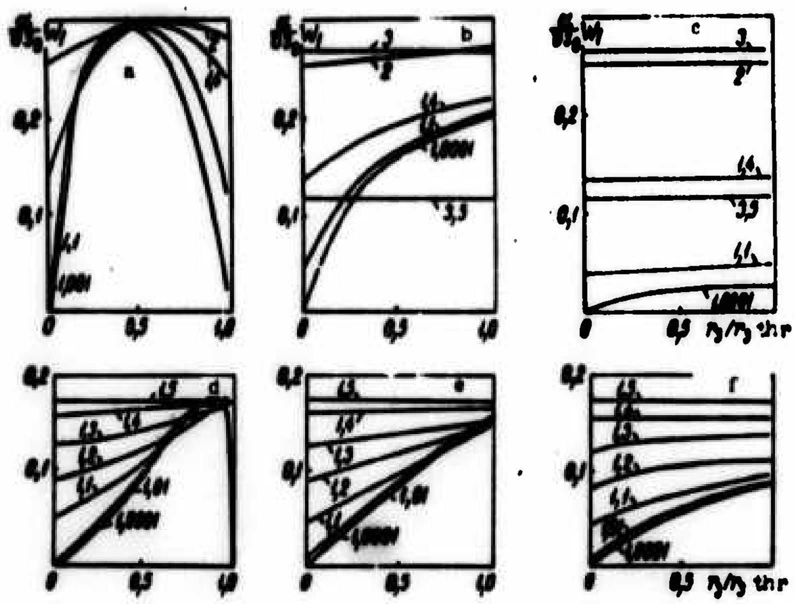

Fig. 2. Dependence of $\frac{\alpha}{vs_0} W_1$ on r_3/r_3^{thr}: a, b, c – for $k_0 = 0.15\ cm^{-1}$; $\rho = 0.02\ cm^{-1}$; $\ell_1 = 5$ cm and for ℓ_2 equal to 5 cm, 20 cm, and 50 cm, respectively; d, e, f – for $k_0 = 0.0015\ cm^{-1}$; $\rho = 2\cdot 10^{-5}$ $\ell_1 = 150$ cm and for ℓ_2 equal to 150 cm, 500 cm, and 1000 cm, respectively. The numbers near the curves are the values of r_2/r_2^{thr}.

Thus, the investigation of the excitation of the generator-amplifier system shows that the mutual influence of the samples in such a composite system should be considered: a) with short lengths of the amplifier less than or equal to the length of the master generator; b) with long lengths of the amplifying layer, but with reflectivities of r_2 close to threshold values r_2^{thr}.

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Received
10 June 1966

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